Section IV: Selected M&V Methods—Option B

The chapters in this section contain descriptions of measure-specific M&V methods associated with Option B. Option B is one of the four M&V options defined for the implementation of federal ESPC projects. The methods described here are for the most typical ECMs, and they are representative of the range of methods available.

Chapter 12 introduces Option B. The measure-specific M&V methods based on Option B are presented here as follows:

Chapter	ECM	Method Number
13	Lighting efficiency	LE-B-01
14	Lighting efficiency	LE-B-02
15	Lighting controls	LC-B-01
16	Lighting controls	LC-B-02
17	Constant-load motor efficiency	CLM-B-01
18	Variable-speed drive retrofit	VSD-B-01
19	Chiller replacements	CH-B-01, CH-B-02
20	Generic variable load projects	GVL-B-01

12

Introduction to Option B

Option B involves a retrofit or system-level M&V assessment. The approach is intended for retrofits with performance factors (e.g. end-use capacity, demand, power) and operational factors (lighting operational hours, cooling ton-hours) that can be measured at the component or system level. It is appropriate to use spot or short-term measurements to determine energy savings when variations in operations are not expected to change. When variations are expected, it is appropriate to measure factors continuously during the contract.

Option B is typically used when any or all of these conditions apply:

- For simple equipment-replacement projects with energy savings that are less than 20% of total facility energy use as recorded by the relevant utility meter or sub-meter.
- When energy savings values per individual measure are desired.
- When interactive effects are to be ignored or are stipulated using estimating methods that do not involve long-term measurements.
- When the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor.
- When sub-meters already exist that record the energy use of subsystems under consideration (e.g., a 277 Volt lighting circuit or a separate submeter for HVAC systems).

12.1 Approach

Option B verification procedures involve the same items as Option A but generally involve more end-use metering. Option B relies on the physical assessment of equipment change-outs to ensure the installation is to specification. The potential to generate savings is verified through observations, inspections, and spot/short-term/continuous metering. The continuous metering of one or more variables may only occur after retrofit installation. Spot or short-term metering may be sufficient to characterize the baseline condition.

12.2 M&V Considerations

Option B is for projects in which (a) the potential to generate savings must be verified and (b) actual energy use during the contract term needs to be measured for comparison with the baseline model for calculating savings. Option B involves procedures for verifying the same items as Option A, plus the determination of energy savings during the contract term through short-term or continuous end-use metering. Option B:

- Confirms that the proper equipment/systems were installed and that they have the potential to generate predicted savings.
- Determines an energy (and cost) savings value using short-term or continuous measurement of performance and operating factors.

All end-use technologies can be verified with Option B; however, the degree of difficulty and costs associated with verification increases as metering complexity increases. Energy savings accuracy is defined by the owner or is negotiated with the ESCO. The task of measuring or determining energy savings using Option B can be more difficult and costly than that of Option A. Results are typically more precise, however, than the use of stipulations as defined for Option A.

Methods involve the use of pre- and post-installation measurement of one or more variables. If operation does not vary between pre and post conditions, monitoring pre-installation operation is not necessary. Spot or short-term measurements of factors are appropriate when variations in loads and operation are not expected. When variations are expected, it is appropriate to measure factors continuously. Performing continuous measurements (i.e. periodic measurements taken over the term of the contract) account for operating variations and will result in closer approximations of actual energy savings. Continuous measurements provide long-term persistence data on the energy use of the equipment or system. These data can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the retrofit. In situations like constant-load retrofits, however, there may be no inherent benefit of continuous over short-term measurements. Measurement of all affected pieces of equipment or systems may not be required if statistically valid sampling is used. For example, population samples may be measured to estimate operating hours for a selected group of lighting fixtures or the power draw of certain constant-load motors that have been predetermined to operate in a similar manner.

13

Lighting Efficiency: Monitoring of Operating Hours

13.1 Project Definition

The lighting projects covered by this verification plan are as follows:

- Retrofits of existing fixtures, lamps, and/or ballasts with an identical number of more energy-efficient fixtures, lamps, and/or ballasts
- De-lamping with or without the use of reflectors.

These lighting efficiency projects reduce demand; however, the fixtures have the same pre- and post-retrofit operating hours.

13.2 Overview of Verification Method

This method is similar to Option A methods LE-A-01 and LE-A-02 in that surveys will be made of all baseline and post-installation lighting fixtures and that fixture wattages will be based on a standard table or measurements. This method differs in that, instead of stipulating operating hours, the operating hours are measured throughout the term of the agreement, either at regular intervals or continuously.

Surveys are required of existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

Fixture wattages will be determined from any of the following:

- A table of standard wattages
- Documentation on each fixture or ballast or lamp combination
- Measurements of representative fixtures or lighting circuits.

Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures and rooms. The monitoring time period must be reasonable and account for any seasonal variations.

This chapter addresses one of two M&V methods under Option B for lighting efficiency projects. Method LE-B-01 requires pre- and post-installation equipment surveys in combination with post-installation metering of hours of operation to estimate savings. Chapter 11 addresses Method LE-B-02, which involves baseline and post-installation lighting circuit measurements to determine both demand and energy savings.

13.3 Calculating Demand and Energy Savings

13.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have an opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, fixture, lamp, and ballast types; usage area designations; counts of operating and non-operating fixtures; and whether the room is air-conditioned and/or heated.

Fixture wattages will be based on a table of standard fixture wattages or spot/short-term metering.

Wattage Table

Fixture wattages will be from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. In the event that a fixture is not in the table, the party conducting the pre-installation equipment survey should either (a) take wattage measurements for a representative sample of fixtures or (b) provide a documented source of the fixture wattages for approval by the other party.

In general, a standard table of fixture wattages should be used for the baseline fixtures, and documented manufacturers' data should be used for post-installation fixtures.

Fixture Wattage Metering

Fixture wattages will be measured. An example of a metering protocol is as follows:

> The ESCO will take 15-minute, true RMS wattage measurements from at least six fixtures representative of the baseline and post-installation fixtures (actual values may vary by application). Readings will be averaged to determine per-fixture wattage values. For post-installation fixtures, readings should be taken only after the new fixtures have been operating for at least 100 hours. Meters used for this task will be calibrated and have an accuracy of ±2% of reading or better.

13.3.2 Adjustments to Baseline Demand

Before the new lighting fixtures are installed, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are *typically operating* but that have broken lamps, ballasts, and/or switches that are *intended for repair.*

A de-lamped fixture is *not* a non-operating fixture; thus, de-lamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or de-lamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. *The adjustment for non-operating fixtures will be limited to a percentage of the total fixture count per facility, e.g., 10%*. If, for example, more than 10% of the total number of fixtures are non-operating, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

13.3.3 Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO and verified by the federal agency. The techniques discussed in part 13.3.1 can be used to inventory the installed equipment.

13.3.4 Operating Hours

To measure post-installation operating hours, three key issues must be defined:

1. The appropriate usage groups and sample sizes for metering each facility or group of similar facilities.
2. Whether lighting circuit measurements or lighting loggers will be used.
3. How long operating hours will be metered to determine a representative operating profile.

Usage Groups

Building usage areas will be identified for areas with comparable average operating hours, as determined by the lights operating during the year or by each of the electric utility's costing periods. Usage areas must be defined in a way that groups together areas that have similar occupancies and lighting operating-hour schedules.

For each unique usage area, the ESCO or federal agency will develop a sampling plan to monitor the average operating hours of either a sample of fixtures or a sample of circuits. Sampling guidelines are in Appendix D.

Meters

The ESCO will specify the meter to be used in the site-specific M&V plan. Measurements of operating hours are typically done with either of these:

- "Light loggers," which are devices that measure the operating hours of individual fixtures through the use of photocells. A wide variety of products are available that store information that can be translated into either elapsed run times for fixtures (run-time loggers) or actual load profiles of on and off times for fixtures (time-of-use loggers)
- Current or power measurements of lighting circuits that, when calibrated to the total connected lighting load on the circuit, can be used to determine how many fixtures were operating in terms of elapsed time or actual time-of-use load profiles.

The meter and recording device may be required to measure and record data indicating operating hours for each all-utility time-of-use costing period. The ESCO must use a data logger that records status at frequent intervals (i.e., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available.

If the ESCO chooses to monitor circuits to determine average operating hours, the ESCO will use run-time or power recording meters that record the circuit on/off pattern in each utility costing period. The ESCO will not monitor circuits when the circuit serving the lighting retrofit load also serves other non lighting loads that cannot be distinguished from the lighting load. Thus, only when lighting and non-lighting loads are separable may circuits be monitored.

Period of Monitoring

Monitoring provides an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operating-hours estimates. Monitoring equipment should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the monitoring installation period, that period should be extended for the same number of days as the holiday or vacation.

If less than continuous monitoring is used, the lighting operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of *three weeks* is recommended for almost all usage-area groups. For situations in which lighting might vary seasonally, such as classrooms, or according to a scheduled activity, it may be necessary to determine lighting operating hours during different times of the year.

The ESCO-supplied site-specific M&V plan will include the detailed the agreed-to sample plan and monitoring plan.

13.4 Equations for Calculating Energy and Demand Savings

For the year of installation payments, the ESCO will provide operating-hour estimates for each usage area. These estimates must be realistic and documented.

Either the federal agency or the ESCO will extrapolate results from the monitored sample to the population to calculate the average operating hours of the lights for every unique usage area. Simple, unweighted averages will be used for each usage area. The assigned party will apply these average operating hours to the baseline and post-installation demand for each usage area to calculate the respective energy savings and peak-period demand savings for each usage area.

The annual baseline energy usage is the sum of the baseline kWh for all of the usage areas. The post-retrofit energy usage is calculated similarly. The energy savings are calculated as the difference between baseline and post-installation energy usage. The operating hours determined each post-installation year will be used for both the baseline and post-installation energy calculations.

13.4.1 Energy

The following equation can be used to determine estimates of energy savings for lighting efficiency projects:

$$\text{kWh Savings}_t = \Sigma_u\left[(\text{kW/Fixture}_{\text{baseline}} \times \text{Quantity}_{\text{baseline}} - \text{kW/Fixture}_{\text{post}} \times \text{Quantity}_{\text{post}}) \times \text{Hours of Operation}\right]_{t,\,u}$$

where:

kWh Savings_t = kilowatt-hour savings realized during the post-installation time period *t*

$\text{kW/Fixture}_{\text{baseline}}$ = lighting baseline demand per fixture for usage group *u*

$\text{kW/Fixture}_{\text{post}}$ = lighting demand per fixture during post-installation period for usage group *u*

$\text{Quantity}_{\text{baseline}}$ = quantity of affected fixtures before the lighting retrofit adjusted for inoperative lighting fixtures for usage group *u*

$\text{Quantity}_{\text{post}}$ = quantity of affected fixtures after the lighting retrofit for usage group u and time period *t*

Hours of Operation = total number of post-installation operating hours (assumes number is the same before and after the lighting retrofit) for usage group *u*.

13.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate and is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction, with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

13.4.3 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space-conditioning systems. However, the reduction in lighting load may also increase space-heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects
- Use agreed-to, “default” interactive values such as a 5% add-on to lighting kWh savings to account for additional air-conditioning saving
- Calculate interactive effects on a site-specific basis.

13.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. In addition, the report includes most of the components in the project pre-installation report, adding information on actual rather than expected ECM installations.

13.6 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC contract between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves the project construction, the ESCO must submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach
- Specification of savings calculations
- Identification of corresponding variables and specification of assumptions
- Identification of data sources and/or collection techniques
- Specification of data collection (i.e., sampling, site inspection, and monitoring plan), if required
- Identification and resolution of any other M&V issues.

Specific M&V issues related to lighting efficiency projects that must be addressed include the following:

- Establishment of baseline fixture wattages at current efficiency standards
- Designation of usage groups and lighting operating hours sampling plans, including accounting for lost data and unique situations at the site that can affect measurements, e.g., double-switched lighting fixtures
- Assessment of non-operating fixtures
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels
- Identification of approach for determining interactive savings.

In addition, project pre- and post-installation reports should identify the specific steps required to implement the M&V plan.

14

Lighting Efficiency: Metering of Lighting Circuits

14.1 Project Definition

The lighting projects covered by this verification plan are as follows:

- Retrofits of existing fixtures, lamps and/or ballasts with an identical number of more energy-efficient fixtures, lamps and/or ballasts
- De-lamping with or without the use of reflectors.

Lighting efficiency projects reduce demand; however, the fixtures have the same pre- and post-retrofit operating hours.

14.2 Overview of Verification Method

This M&V method involves measuring all, or a representative number of, lighting circuits to determine either or both of the following:

- Baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and average demand savings
- Baseline and post-installation electrical demand (kW) profiles in order to determine demand savings.

Circuit measurements may be made of current flow (amperage) or power draw (wattage) per unit of time. The post-installation metering time period may be continuous or for a reasonable, limited period of time during each contract year.

Surveys are suggested for existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating baseline fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

This chapter addresses one of two M&V methods under Option B for lighting efficiency projects. Method LE-B-01 requires pre- and post-installation equipment surveys in combination with post-installation monitoring of hours of operation for establishing savings. Method LE-B-02 involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings.

14.3 Calculating Demand and Energy Savings

14.3.1 Baseline Demand and Energy

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, then the ESCO will have an opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Circuit measurements are the basis for calculating energy and demand savings with this M&V method. Equipment inventories, however, are strongly suggested to confirm proper equipment installation, as a check against circuit measurements, and as documentation for any changes that may be required in the definition of the baseline due to future retrofits or other changes. In addition, the survey is used to quantify non-operating fixtures for any required adjustments to the baseline and post-installation circuit measurements, as discussed below in part 14.3.2.

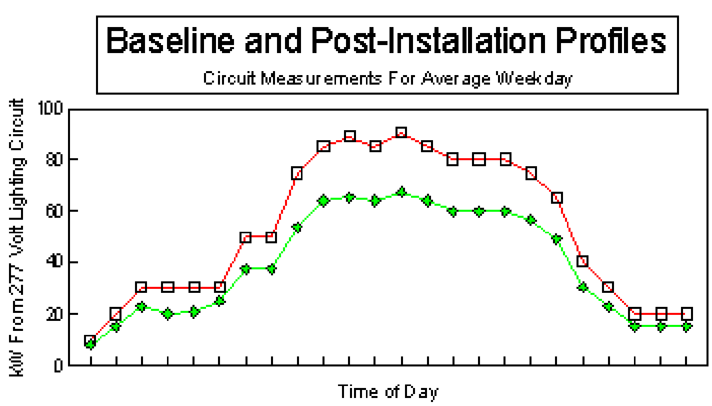
Pre-Installation Equipment Survey

In a pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed for the facility or set of facilities under the project are inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys should include, in a set format, fixture, lamp and ballast types, usage area designations, counts of operating and non-operating fixtures, and whether the room is air-conditioned and/or heated.

Circuit Measurements

Circuit measurements are made to measure either power draw or current flow (as a proxy for power draw) on one or more circuits that have only (or primarily) lighting loads. The measurements are made before and after the lighting retrofit is completed. By comparing the power on the circuits before and after the retrofit, both energy and demand savings can be determined. Figure 14.1 compares average load profiles for a lighting circuit's energy draw before and after a retrofit. Such curves can be based on, for example, two weeks' worth of measurements that are averaged into a single daily baseline and post-installation profile.

Figure 14.1: Typical Lighting Load Profiles



The circuits must be carefully selected to ensure the following:

- Only lighting loads that are affected by the retrofit are on the measured circuit(s) (typically, 277-V circuits are used).
- If other loads are on the circuit(s), the non-lighting loads should be minimal, and well defined, and they should not vary from before the retrofit to after it is complete.

If only a subset of affected lighting circuits are metered, the following issues must be addressed:

- Which lighting loads are on each lighting circuit?
- Which lighting circuits are representative of the entire facility, certain areas, or certain lighting usage groups?
- What are the appropriate lighting circuit sample sizes?

Whether all the circuits or just a sample of them are metered, it is important to specify how long the metering will be conducted in order to determine a representative baseline and post-installation operating profile.

For each facility, the ESCO or federal agency will develop a sampling plan for monitoring circuits. The sampling plan may concentrate measurements in areas with the greatest savings.

Meters

The ESCO will specify the meter to be used in the site-specific M&V plan. Measurements of circuits are typically made with either of the following:

- Current transducers connected to one or more legs of a lighting circuit. Current data measurements are taken over an extended period of time. Voltage and power factor data are taken as spot measurements and then assumed to be constant during the time period of the current metering. True RMS readings are preferred.
- True RMS current and potential (voltage) transducers used to measure power continuously during the time period of circuit monitoring. This type of metering can be more accurate than just current measurement, but it is also more expensive.

The meter and recording device may be required to measure and record data for all utility time-of-use costing periods. The ESCO should use a data logger that records status at frequent intervals (e.g., at least every 15 minutes). “Raw” as well as “compiled” data from the meter(s) must be made available to the federal agency.

Period of Monitoring

Metering provides an estimate of demand profiles and annual energy use. The duration and timing of the installation of circuit monitors have a strong influence on the accuracy of energy savings estimates. Metering should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the metering installation period, the metering period should be extended as many days as the holiday or vacation lasted.

If less than continuous metering is used, the energy use and demand profiles obtained during the metered period will be extrapolated to the full year. A minimum metering period of three weeks is recommended for almost all situations. For situations in which lighting might vary seasonally, such as classrooms, or according to a scheduled activity, it may be necessary to determine lighting energy use and profiles during different times of the year.

The ESCO-supplied site-specific M&V plan will include a detailed, agreed-to sample plan and metering plan.

14.3.2 Adjustments to Baseline Demand

Before new lighting fixtures are installed, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

The party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are *typically operating* but have broken lamps, ballasts, and/or switches that are *intended for repair.*

A de-lamped fixture is not a non-operating fixture; thus, de-lamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or de-lamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. *The adjustment for inoperative fixtures will be limited to some percentage of the total fixture count per facility, e.g., 10%*. If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

14.3.3 Post-Installation Demand

The post-installation conditions should be identified in the post-installation equipment survey, which is typically prepared by the ESCO and verified by the federal agency. The circuit measurements are then used to define post-installation demand and energy, as discussed above.

14.4 Equations for Calculating Energy and Demand Savings

For the year of installation payments, the ESCO will provide energy and demand savings estimates. These estimates must be realistic and documented. Either the federal agency or the ESCO will extrapolate results from the metering data to determine demand and energy savings.

14.4.1 Energy

To determine estimates of energy savings for lighting efficiency projects, use the following equation:

$$\text{kWh Savings}_t = (\text{Average kWh}_{\text{baseline}})_t - (\text{Average kWh}_{\text{post}})_t$$

where:

kWh Savings $_t$ = the kilowatt-hour savings realized during the time period *t*, where *t* can be a whole year, a week, weekdays, weekends, or a particular hour of the day

$(\text{Average kWh}_{\text{baseline}})_t$ = the lighting baseline energy use averaged for all the time period *t* measurements

$(\text{Average kWh}_{\text{post}})_t$ = the lighting post-installation energy use averaged for all the time period *t* measurements.

Implicit in this equation is the assumption that baseline and post-installation lighting operating hours are the same.

14.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak-load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill, and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

14.4.3 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space-conditioning systems; however, the reduction in lighting load may also increase space heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects.
- Use agreed-to, "default" interactive values such as a 5% add on to lighting kWh savings to account for additional air-conditioning saving.
- Calculate interactive affects on a site-specific basis.

14.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes the following:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify a agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the components in the project pre-installation report, adding information on *actual* rather than expected ECM installations.

14.6 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves project construction, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations

- Identification of corresponding variables and specification of assumptions
- Identification of data sources and/or collection techniques
- Specification of data collection (i.e., sampling, site inspection, and monitoring plan), if required
- Identification and resolution of any other M&V issues.

Specific M&V issues related to lighting efficiency projects that need to be addressed include the following:

- Establishment of baseline fixture wattages at current efficiency standards
- Selection of lighting circuits to be metered
- Selection of metering equipment
- Selection of time period for metering
- Assessment of non-operating fixtures
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels
- Identification of approach for determining interactive savings.

In addition, project pre- and post-installation reports should identify the specific steps required to implement the M&V plan.

15

Lighting Controls: Monitoring of Operating Hours

15.1 Project Definition

The lighting projects covered by this M&V plan are installation of occupancy sensors or daylighting controls with or without changes to fixtures, lamps, or ballasts.

These lighting control projects reduce fixture operating hours.

15.2 Overview of Verification Method

This method is similar to Option A methods LC-A-01 and LC-A-02, in that surveys will be made of all baseline and post-installation lighting fixtures and controls and fixture wattages will be measured on a standard table of measurements. The difference is that, instead of stipulating operating hours, the operating hours are measured throughout the term of the agreement either at regular intervals or continuously.

Surveys are required of existing (baseline) and new (post-installation) fixtures and controls. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

Fixture wattages will be determined from any of the following:

- Measurements of representative fixtures or lighting circuits
- Documentation on each fixture or ballast or lamp combination
- A table of standard wattages.

Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures and rooms. The monitoring time period must be reasonable and account for any seasonal variations.

This chapter addresses one of two M&V methods under Option B for lighting control projects. Method LC-B-01 requires pre- and post-installation equipment surveys in combination with pre- and post-installation metering of hours of operation to establish savings. Chapter 16 addresses method LC-B-02, which involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings.

15.3 Calculating Demand and Energy Savings

15.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have an opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed (if an efficiency retrofit is to be done concurrently) are inventoried. Room locations and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, fixture, lamp, and ballast types; lighting controls; usage area designations; counts of operating and non-operating fixtures; and whether the room is air-conditioned and/or heated.

Fixture wattages will be based on a table of standard fixture wattages or spot/short-term metering.

Wattage Table

Fixture wattages will be determined from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. If a fixture is not in the table, the party conducting the pre-installation equipment survey should either (a) take wattage measurements for a representative sample of fixtures, or (b) provide a documented source of the fixture wattages for approval by the other party.

In general, a standard table of fixture wattages should be used for the baseline fixtures, and documented manufacturers' data should be used for post-installation fixtures.

Fixture Wattage Metering

Fixture wattages will be measured. An example of a metering protocol is as follows:

> The ESCO will take 15-minute, true RMS wattage measurements from at least six fixtures representative of the baseline and post-installation fixtures (actual values may vary by application). Readings will be averaged to determine per-fixture wattage values. For post-installation fixtures, readings should be taken only after the new fixtures have been operating for at least 100 hours. Meters used for this task will be calibrated and have an accuracy of ±2% of reading, or better.

15.3.2 Adjustments to Baseline Demand

Before new lighting fixtures are installed, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy.

Methods for making adjustments should be specified in the site-specific M&V plan.

The party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are *typically operating* but that have broken lamps, ballasts, and/or switches that are *intended for repair.*

A de-lamped fixture is not a non-operating fixture; thus, de-lamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or de-lamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. *The adjustment for inoperative fixtures will be limited to a percentage of the total fixture count per facility, e.g., 10%.* If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

15.3.3 Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO and verified by the federal agency. The techniques discussed in part 15.3.1 can be used to inventory the installed equipment.

15.3.4 Operating Hours

To determine how operating hours will be measured (both before and after the control devices are installed), three key issues must be defined:

- The appropriate usage groups and sample sizes for metering each facility or group of similar facilities
- Whether lighting circuit measurements or lighting loggers will be used
- How long the operating hours should be metered to determine a representative operating profile.

Usage Groups

Building usage areas will be identified for those areas with comparable average operating hours, as determined by the lights operating during the year or by each of the electric utility's costing periods. Usage areas must be defined in a way that groups together areas that have similar occupancies and lighting operating hour schedules.

For each unique usage area, the ESCO or federal agency will develop a sampling plan to monitor the average operating hours of either a sample of fixtures or a sample of circuits. Sampling guidelines are provided in Appendix D.

Meters

The ESCO will specify the meter to be used in the site-specific M&V plan. Operating hours are typically measured with either of the following:

- "Light loggers," which are devices that measure the operating hours of individual fixtures through the use of photocells. A wide variety of products are available that store information that can be translated into either elapsed run times for fixtures (run-time loggers) or actual load profiles of on and off times for fixtures (time-of-use loggers).
- Current or power measurements of lighting circuits, which, when calibrated to the total connected lighting load on the circuit, can be used to determine how many fixtures were operating in terms of elapsed time over a period of time or actual time-of-use load profiles.

The meter and recording device may be required to measure and record data for all utility time-of-use costing periods. The ESCO must use a data logger that records status at frequent intervals (e.g., at least every 15 minutes). "Raw" as well as compiled" data from the meter(s) must be made available to the federal agency.

If the ESCO chooses to monitor circuits to determine average operating hours, the ESCO will use run-time or power recording meters that record the circuit on/off pattern in each utility costing period. The ESCO will *not* monitor circuits when the circuit serving the lighting retrofit load also serves other non-lighting loads that cannot be distinguished from the lighting load. Thus, only when lighting and non-lighting loads are separable, may circuits be monitored.

Period of Monitoring

Monitoring provides an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operating hours estimates. Run-time monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the run-time monitoring installation period, the duration of monitoring should be extended for as many days as the holiday or vacation lasted.

If less than continuous monitoring is used, the lighting operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of *three weeks* is recommended for almost all usage area groups. For situations in which lighting might vary seasonally, such as classrooms, or according to a scheduled activity, it may be necessary to determine lighting operation hours during different times of the year.

The ESCO supplied site-specific M&V plan will include the detailed, agreed-to sample plan and monitoring plan.

15.4 Equations for Calculating Energy and Demand Savings

For the year of installation payments, the ESCO will provide operating-hour estimates for each usage area. These estimates must be realistic and documented.

Either the federal agency or the ESCO will extrapolate results from the monitored sample to the population to calculate the average operating hours of the lights for every unique usage area. Simple, unweighted averages will be used for each usage area. To calculate the respective energy savings and peak period demand savings for each usage area, the assigned party will apply these average operating hours to the baseline and post-installation demand for each usage area.

The annual baseline energy usage is the sum of the baseline kWh for all of the usage areas. The post-retrofit energy usage is calculated similarly. The energy savings are calculated as the difference between baseline and post-installation energy usage. The operating hours determined each post-installation year will be used for both the baseline and post-installation energy calculations.

To avoid double-counting the savings from energy-efficiency projects that also have lighting control projects applied, the ESCO will meter the pre-installation and post-installation controlled hours of operation as the basis for calculating lighting efficiency savings. See below for calculations.

15.4.1 Energy

To avoid double-counting lighting efficiency and control projects' savings, the savings equations for both types of projects are combined into a single equation:

$$\text{kWh Savings}_t = \Sigma_u[(\text{kW/Fixture} \times \text{Quantity} \times \text{Hours of Operation})_{\text{baseline}} \\ -(\text{kWh/Fixture} \times \text{Quantity} \times \text{Hours of Operation})_{\text{post}}]_{t,\,u}$$

where:

kWh Savings_t = kilowatt-hour savings realized during the post-installation time period t

$\text{kW/Fixture}_{\text{baseline}}$ = lighting baseline demand per fixture

$\text{kW/Fixture}_{\text{post}}$ = lighting demand per fixture during post-installation period for usage group u

$\text{Quantity}_{\text{baseline}}$ = the quantity of affected fixtures before the lighting retrofit adjusted for inoperative and non-operative lighting fixtures for usage group u

$\text{Quantity}_{\text{post}}$ = quantity of affected fixtures after the lighting retrofit for usage group u

Hours of $\text{Operation}_{\text{baseline}}$ = total number of operating hours during the pre-installation period for usage group u

Hours of $\text{Operation}_{\text{post}}$ = total number of operating hours during the post-installation period for usage group u.

This equation is based on the following:

- Savings for energy efficiency lighting projects as defined in the following equation:

$$\text{kWh Savings} = \Sigma_u([(\text{kW/Fixture} \times \text{Quantity})_{\text{baseline}} - (\text{kW/Fixture} \times \text{Quantity})_{\text{post}}] \times \text{Hours of Operation}_{\text{post}})_{t,u}$$

- Savings for lighting control projects as defined in the following equation:

$$\text{kWh Savings} = \Sigma_u [(\text{Hours of Operation}_{\text{baseline}} - \text{Hours of Operation}_{\text{post}}) \times (\text{kW/Fixture} \times \text{Quantity}_{\text{baseline}})]_{t,u}$$

15.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction with respect to cost savings is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak-load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill, and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

15.5 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space-conditioning systems; however, the reduction in lighting load may also increase space-heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects
- Use agreed-to, "default" interactive values such as a 5% adder to lighting kWh savings to account for additional air-conditioning saving
- Calculate interactive affects on a site-specific basis.

15.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes the following:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the project pre-installation report, adding information on *actual* rather than expected ECM installations.

15.7 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations
- Identification of corresponding variables and specification of assumptions
- Identification of data sources and/or collection techniques
- Specification of data collection (i.e., sampling site inspection, and monitoring plan), if required
- Identification and resolution of any other M&V issues.

Specific M&V issues that must be addressed related to lighting efficiency projects include the following:

- Decision whether to establish baseline fixture wattages at current efficiency standards
- Avoiding double-counting the savings from energy-efficiency projects that are controlled
- Designation of usage groups and lighting operating hours sampling plans, including accounting for lost data and unique situations at the site that can affect measurements; e.g., double-switched lighting fixtures
- Assessment of non-operating fixtures
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels, and identification of approach for determining interactive savings.

16

Lighting Controls: Metering of Lighting Circuits

16.1 Project Definition

The lighting projects covered by this verification plan are installations of occupancy sensors or daylighting controls with or without changes to fixtures, lamps, or ballasts.

These lighting controls projects reduce fixture operating hours.

16.2 Overview of Verification Method

This M&V method involves measuring all, or a representative number of, lighting circuits to determine either or both of the following:

- Baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and average demand savings
- Baseline and post-installation electrical demand (kW) profiles in order to determine demand savings.

Circuit measurements may be made of current flow (amperage) or power draw (wattage) per unit of time. The post-installation metering time period may be continuous or for a reasonable, limited period of time during each contract year.

Surveys are suggested for existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating baseline fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

This chapter addresses one of two M&V methods under Option B for lighting controls projects. Method LC-B-02 involves baseline and post-installation lighting circuit measurements to determine both demand and energy savings. The previous chapter address method LC-B-01, which requires pre- and post-installation equipment surveys in combination with baseline and post-installation monitoring of hours of operation for establishing savings.

16.3 Calculating Demand and Energy Savings

16.3.1 Baseline Demand and Energy

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have an opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

The basis for calculating energy and demand savings with this M&V method is circuit measurements. Equipment inventories, however, are strongly suggested to confirm proper equipment installation, as a check against circuit measurements, and as documentation for any changes that may be required in the definition of the baseline due to future retrofits or other changes. In addition, the survey is used to quantify non-operating fixtures for any required adjustments to the baseline and post-installation circuit measurements, as discussed below in part 16.3.2.

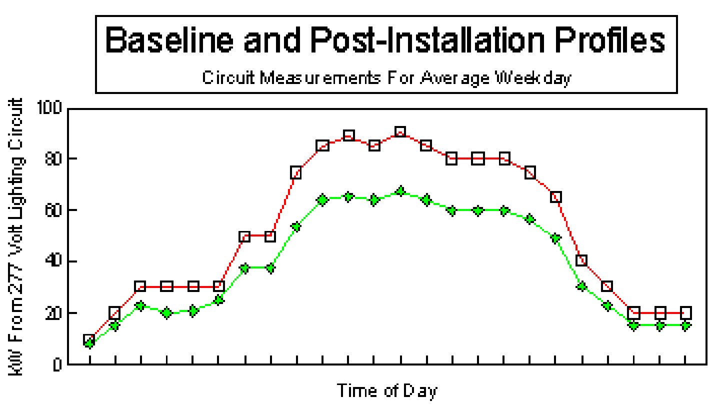
Pre-Installation Equipment Survey

In a pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed in the facility or set of facilities under the project are inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys should include, in a set format, fixture, lamp and ballast types, usage area designations, counts of operating and non-operating fixtures, and whether the room is air-conditioned and/or heated.

Circuit Measurements

Circuit measurements measure either power draw or current flow (as a proxy for power draw) on one or more circuits that have only (or primarily) lighting loads. Measurements are made before and after the lighting retrofit is completed. Comparing the power on the circuits before and after the retrofit determines both energy and demand savings. Figure 16.1 compares average load profiles for the energy draw of a lighting circuit both before and after a retrofit. Such curves can be based on, for example, two weeks' worth of measurements that are averaged into a single daily baseline and post-installation profile.

Figure 16.1: Typical Lighting Load Profiles



The circuits must be carefully selected to ensure either of the following:

- Only lighting loads that are affected by the retrofit are on the measurement circuit(s) (typically 277-V circuits are used).
- If other loads are on the circuit(s), the non-lighting loads should be minimal, well defined, and not vary from before the retrofit is complete to after it is complete.

If only a subset of affected lighting circuits is metered, the following issues must be addressed:

- Which lighting loads are on each lighting circuit?
- Which lighting circuits are representative of the entire facility, certain areas, or certain lighting usage groups?
- What are the appropriate lighting circuit sample sizes?

Whether all or just a sample of circuits are metered, it is important to specify how long the metering will be conducted in order to determine a representative baseline and post-installation operating profile.

For each facility, the ESCO or federal agency will develop a sampling plan for monitoring circuits. The sampling plan may concentrate measurements in areas with the greatest savings.

Meters

The ESCO will specify the meter to be used in the site-specific M&V plan. Circuits are typically measured with either of the following:

- Current transducers connected to one or more legs of a lighting circuit. Current data measurements are taken over an extended period of time. Voltage and power factor data are taken as spot measurements and then assumed to be constant during the time period of the current metering. True RMS readings are preferred.
- True RMS current and potential (voltage) transducers are used to measure power continuously during the time period of circuit monitoring. This type of metering can be more accurate than just current measurement, but it is also more expensive.

The meter and recording device may be required to measure and record data for all utility time-of-use costing periods. The ESCO should use a data logger that records status at frequent intervals (e.g., at least every 15 minutes). “Raw” as well as “compiled” data from the meter(s) must be made available to the federal agency.

Period of Metering

Metering is intended to provide an estimate of demand profiles and annual energy use. The duration and timing of the installation of circuit metering have a strong influence on the accuracy of energy savings estimates. Metering should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the metering installation period, the duration of metering should be extended for as many days as the holiday lasted.

If less than continuous metering is used, the energy use and demand profiles obtained during the monitored period will be extrapolated to the full year. A minimum metering period of *three weeks* is recommended for almost all situations. For situations in which lighting might vary seasonally, such as in classrooms, or according to a scheduled activity, it may be necessary to determine lighting energy use and profiles during different times of the year.

The ESCO-supplied site-specific M&V plan will include a detailed, agreed-to sample plan and metering plan.

16.3.2 Adjustments to Baseline Demand

Before the new lighting fixtures are installed, adjustments to the baseline demand may be required for non-operating fixtures. After the ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

The party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are *typically operating* but that have broken lamps, ballasts, and/or switches that are *intended for repair.*

A de-lamped fixture is not a non-operating fixture; thus, de-lamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or de-lamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. *The adjustment for inoperative fixtures will be limited to a percentage of the total fixture count per facility, e.g., 10%*. If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

16.3.3 Post-Installation Demand

The post-installation conditions should be identified in the post-installation equipment survey, which is typically prepared by the ESCO and verified by the federal agency. The circuit measurements are then used to define post-installation demand and energy, as discussed above.

16.4 Equations for Calculating Energy and Demand Savings

For the year of installation payments, the ESCO will provide energy and demand savings estimates. These estimates must be realistic and documented.

Either the federal agency or the ESCO will extrapolate results from the metering data to determine demand and energy savings.

16.4.1 Energy

To determine estimates of energy savings for lighting controls projects, use the following equation:

$$\text{kWh Savings}_t = (\text{Average kWh}_{\text{baseline}})_t - (\text{Average kWh}_{\text{post}})_t$$

where:

kWh Savings_t = the kilowatt-hour savings realized during the time period *t*, where *t* can be a whole year, a week, weekdays, weekends, or a particular hour of the day

$(\text{Average kWh}_{\text{baseline}})_t$ = the lighting baseline energy use averaged for all the time period *t* measurements

$(\text{Average kWh}_{\text{post}})_t$ = the lighting post-installation energy use averaged for all the time period *t* measurements.

Implicit in this equation is the assumption that baseline and post-installation lighting operating hours are the same.

16.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction is the largest reduction in demand that occurs from the retrofit during a specified period of time. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define how the reduction will affect the utility bill and how the demand reduction will be calculated for purposes of payments to ESCOs.

16.4.3 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space-conditioning systems; however, the reduction in lighting load may also increase space-heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects
- Use agreed-to, "default" interactive values such as a 5% adder to lighting kWh savings to account for additional air conditioning savings
- Calculate interactive affects on a site-specific basis.

16.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes the following:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the project pre-installation report, adding information on actual rather than expected ECM installations.

16.6 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves the project construction, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations

- Identification of corresponding variables and specification of assumptions
- Identification of data sources and/or collection techniques
- Specification of data collection (i.e., sampling, site inspection, and monitoring plan), if required
- Identification and resolution of any other M&V issues.

Specific M&V issues related to lighting efficiency projects that must be addressed include the following:

- Establishment of baseline fixture wattages at current efficiency standards
- Avoiding double-counting the savings from energy-efficiency projects that are controlled
- Selection of lighting circuits to be metered
- Selection of metering equipment
- Selection of time period for metering
- Assessment of non-operating fixtures
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels
- Identification of the approach for determining interactive savings.

In addition, project pre- and post-installation reports should identify the specific steps required to implement the M&V plan.

17

Constant-Load Motor Efficiency: Metering of Operating Hours

17.1 ECM Definition

Constant-load motor efficiency projects involve the replacement of existing (baseline) motors with high-efficiency motors that serve constant-load systems. These ECMs are called constant-load motor efficiency projects because the power draw of the motors does not vary over time. These projects reduce demand and energy use.

This M&V method is appropriate only for projects in which constant-load motors are replaced with similar capacity constant-speed motors, with two exceptions:

- Baseline motors may be replaced with smaller high-efficiency motors when the original motor was oversized for the load.
- Constant-speed motor drives may be adjusted to account for the difference in slip between the baseline motor and the high-efficiency motor.

If motor changes are accompanied by a change in operating schedule, a change in flow rate, or the installation of variable-speed controls, other M&V methods are more appropriate.

17.2 Overview of Verification Method

Under Option B, method CLM-B-01 is the only specified technique for verifying constant-load motor efficiency projects. Surveys are required to document existing (baseline) and new (post-installation) motors. The surveys should include the following (in a set format) for each motor:

- Nameplate data
- Operating schedule
- Spot and short-term metering data
- Motor application definitions
- Location.

Metering is required on at least a sample of motors to determine average power draw for baseline and new motors. Demand savings are based on the average kW measured before the new motors are installed minus the average kW measured after they are installed. Allowances may be made for differences in motor slip between existing and new motors.

Operating hours for the baseline and/or post-installation periods will be determined with short-term or long-term metering on at least a sample of the motors. In addition, metering can be used to (a) confirm constant loading and (b) determine average motor power draw (if normalization is required).

17.3 Calculating Demand and Energy Savings

17.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are as follows:

- Conduct a pre-installation equipment survey
- Perform spot metering of existing motors
- Perform short-term metering of existing motors.

The equipment survey is described in this subsection. Spot and short-term metering are discussed in part 16.5, as these types of metering activities are also required during the post-installation period.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Motor location and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format:

- Nameplate data
- Motor horsepower
- Load served
- Operating schedule
- Spot and short-term metering data (3-phase amps, volts, PF, kVA, kW and motor speed in rpm)
- Motor application
- Location.

Sample survey forms are included in Appendix C. Table M1 is the pre-installation survey form.

The spot metering measures the instantaneous power draw of the motors. The short-term metering establishes that the motor load is constant, to determine "normalizing factors" for motor power draw, and, possibly, for determining operating hours.

17.3.2 Adjustments to Baseline Demand

Before the new motors are installed, adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation. In addition, after ECM installation, adjustments to baseline demand may be required because of factors such as remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

The party responsible for defining the baseline will also identify any non-operating motors. Non-operating equipment is equipment that is *typically operating* but that has broken parts and is *intended for repair.*

17.3.3 Baseline Operating Hours

Baseline motor operating hours can be determined in either of these ways:

- *Prior* to ECM installation if the hours are assumed to be different than post-installation operating hours
- *After* ECM installation if the hours are assumed to be the same as the post-installation operating hours.

Short-term or long-term metering will be used to determine operating hours, as discussed in subsection 17.6.

17.3.4 Post-Installation Demand

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency. After high-efficiency motors are installed:

- All the motors will be surveyed using the same reporting format as the one used for the baseline motors.
- All motors should be spot metered using the same meter and procedures used for the baseline motors.

See part 17.3.1 for details.

If existing motors were short-term metered, the replacement, high-efficiency motors will also be subject to short-term metering. The data need be processed only to normalize the spot-metering results (as discussed in part 17.5). There is no need to verify that the motor load is constant for the high-efficiency motors.

17.3.5 Post-Installation Operating Hours

Post-installation operating hours can be assumed to be either the same as or different from pre-installation operating hours. If the hours are assumed to be the same before and after the new motors are installed, either pre-installation or post-installation monitoring can be used. If the hours are assumed to be different, however, post-installation monitoring must also be done. Typically, where hours are the same before and after installation, post-installation monitoring will be used because motor installation can proceed without delay due to monitoring.

Operating-hours monitoring is discussed in part 17.6.

17.4 Changes in Load Factor and Slip

Standard-efficiency motors and high-efficiency motors may rotate at different rates when serving the same load. Such differences in rotational speed, characterized as "slip," may lead to smaller savings than expected. Considerable impacts on savings due to slip may be reflected in the difference in load factor between the existing motor and a new high-efficiency motor. Large differences in load factor between the existing motor and the replacement high-efficiency motor may also be symptomatic of other problems. The ESCO will identify motors for which the difference in load factor between the high-efficiency motor and the baseline motor is greater than 10%. If the load factor is outside that range, the ESCO will provide an explanation, with supporting calculations and documentation.

Acceptable reasons for changes in load factor greater than 10% may include these factors:

- The high-efficiency motor is smaller than the original baseline motor. The ESCO will provide documentation that demonstrates that the difference in load factor is due to differences in motor size.
- The high-efficiency motor exhibits less slip and is operating at a higher speed than the baseline motor. The ESCO will provide calculations and documentation that demonstrate that the change in slip accounts for the difference in load factor. (On centrifugal loads, changes in RPM are governed by the "cube-law.") The ESCO is encouraged to account for slip when selecting motors and preparing initial savings calculations or modifying motor drive systems where appropriate.

17.5 Spot and Short-Term Metering

17.5.1 Spot Metering

For each baseline and new motor, spot metering (i.e., instantaneous measurements) of volts, amperes, kVA, PF, and kW should be recorded. These data should be entered into a form such as Table M2 (in Appendix C). Such measurements should be made using a true RMS meter with an accuracy at or approaching ±1% of reading.[1] Other factors to measure include motor speed in rpm and the working fluid temperature if the motor serves a fan or pump. The temperature measurement may be taken at either the inlet or outlet of the device as long as the location is identical for the baseline and post-installation measurements.

17.5.2 Short-Term Metering

The ESCO will conduct short-term monitoring to do the following:

- Verify that motor loads are constant (baseline only).
- Normalize spot-metering kW measurement results.
- Determine operating hours, as discussed in part 17.6.

The ESCO will conduct short-term metering on all baseline and new motors or a randomly selected sample of motors with the same application and/or operating hours. Short-term metering should be summarized in a form such as Table M3 in Appendix B. Sample selection and results of metering for the entire sample should be summarized as shown in Table M4 in Appendix B.

ESCOs may conduct short-term metering using current transducers and data loggers. The equipment for short-term metering need be accurate only within ±5% of full scale, but it must be calibrated against the spot-metering equipment specified above by taking spot-metering readings at the same time. Thus, short-term metering equipment must be installed at the same time spot-metering readings are being taken. Data loggers will record readings at intervals of 15 minutes or less. Note that motor load and kW do not correlate in a linear way with amperage across the full operating range of most motors.

The transducer installation and calibration report and data logger reports in Appendix B should be completed as part of this metering activity.

Verify Constant Load

The ESCO will verify that motor loads are constant by comparing the average amperes measured in the short-term metering period with all hourly non-zero values. An application will be verified to be constant if 90% of all non-zero observations are within ±10% of these average amperes. The ESCO will record the number of non-zero observations, the number of observations within ±10% of the average amperes, and the percent of observations within ±10% of the average amperes. If any application cannot be verified for constant load, the ESCO will examine the collected data to determine whether the load for the motor varies on a systematic and predictable basis, whether the constant load was changed during the test period, or whether there is some system anomaly.

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1. Gordon et. al. reported that on the average, for all qualifying motors, the change in efficiency between a standard-efficiency motor and a high-efficiency motor, including an adjustment for slip, was 4.4%. As such, the resolution of meters used to measure instantaneous kW should be much smaller than 4.0%. (Gordon, F.M. et. al. Impacts of Performance Factors on Savings From Motors Replacement and New Motor Programs. ACEEE 1994 Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy, 1994.)

If the load varies on a systematic basis, the motor will be treated as a variable load. If the load was changed during the short-term monitoring period, spot metering and short-term monitoring testing will be repeated. If a system anomaly is discovered, the ESCO will investigate the anomaly to determine whether there is a logical explanation. Once the anomaly is understood, the ESCO will either treat the load as a variable load or re-test it as a constant load.

Normalize Spot-Metering kW Measurement Results

To determine the average power draw of the replaced or new motors, the spot kW measurements must be adjusted and normalized using short-term measurement data. To develop factors to normalize spot-metering wattage measurements, the ESCO will begin short-term metering by taking measurements at the same moment as the spot metering. The ESCO will enter the spot values in Table M3, in the row titled "Instantaneous Amps." At the conclusion of the short-term metering period, the ESCO will determine the average ampere value during times of motor operation, i.e., the sum of all non-zero observations divided by the number of observations. The ESCO will also enter this value in Table M3. The ESCO will then calculate the "Normalizing Factor" with the following equation:

$$\text{Normalizing Factor} = \frac{\text{Average amps measured during short-term metering}}{\text{Instantaneous amps measured with spot metering}}$$

During the short-term metering, the ESCO will test each motor by modulating the applicable systems over their normal operating range (e.g., low cooling load to peak cooling load, economizer operation, low heating load to peak heating load, minimum output of process product to peak output of process product). Such testing will serve to verify (or not) that, over the full range of normal system operation, motor load remains fairly constant.

For each motor replaced, the ESCO will then calculate average or normalized kW, using the following equation:

$$\text{Normalized kW} = \text{Instantaneous kW} \times \text{Normalizing Factor}$$

For motors that were not subject to short-term metering, the normalizing factor is equivalent to the average normalizing factor developed for the motor sample of the same application (Table M4).

17.6 Monitoring to Determine Operating Hours

Operating hours may be the same before and after the new motors are installed, or the hours may be different. Operating hours for the baseline and/or post-installation period will be determined with short-term or long-term monitoring on at least a sample of motors.

The ESCO will conduct short-term monitoring for a period of time to be specified in the site-specific M&V plan. The period of time will be proposed by the ESCO and approved or modified by the federal agency.

Monitoring is intended to provide an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operating-hours estimates. Run-time monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the run-time monitoring installation period, the duration should be extended as many days as the holiday or vacation lasted.

If less than continuous monitoring is used, the operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of three weeks is recommended for almost all usage-area groups. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, as they do with HVAC systems, it may be necessary to determine operating hours during different times of the year.

17.7 Sampling

The ESCO will spot meter all of the motors. However, the short- or long-term metering to determine (a) that the load is constant, (b) the normalizing factors, and (c) the monitoring operating hours may need to be done only for a sample of motors.

ESCOs will begin their sampling analyses with a classification of existing motors by applications with identical operating characteristics and/or expected operating hours. Examples of applications include HVAC constant volume supply fans, cooling water pumps, heating water pumps, condenser water pumps, HVAC constant-volume return fans, and exhaust fans. Each application will be defined and supported with schematics of ductwork and/or piping, as well as control sequences to demonstrate that the application qualifies as a constant load.

For each application or usage group in the ESCO's program, there must be at least one motor subject to short-term metering.

17.8 Equations for Calculating Energy and Demand Savings

Calculate normalized kW using the following equation:

$$kW_{normalized} = \text{Instantaneous kW (from spot metering)} \times \text{Normalizing Factor}$$

Calculate the kWh savings using the following equations:

- If operating hours are the same before and after ECM installation:

$$\begin{aligned} &\text{kWh Savings (per each period)} \\ &= \text{Period Hours} \times (kW_{baseline,\ normalized} - kW_{post,\ normalized}) \end{aligned}$$

- If operating hours are different before and after ECM installation:

$$\text{kWh Savings (per each period)} = \text{Baseline Period Hours} \times kW_{\text{baseline, normalized}} - \text{Post-Installation Period Hours} \times kW_{\text{post, normalized}}$$

where:

$kW_{\text{baseline, normalized}}$ = the normalized kilowatts for the baseline motors

$kW_{\text{post, normalized}}$ = the normalized kilowatts for the high-efficiency motors

Period Hours = measured hours for a defined time segment, e.g., operating hours per year or hours per utility peak period.

These values may be corrected for changes in motor speed (slip); see part 17.4.

Demand savings may be calculated as follows:

- Maximum demand reduction:

$$\text{kW Savings}_{\text{max}} = (kW_{\text{baseline, normalized}} - kW_{\text{post, normalized}})_t$$

- Average demand reduction:

$$\text{kW Savings}_{\text{avg}} = \frac{\text{kWh Savings per Period}}{\text{Period Hours}}$$

17.9 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes the following:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the project pre-installation report, adding information on *actual* rather than expected ECM installations.

17.10 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves the project construction, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations
- Source of stipulated motor operating hours
- Specification of site survey plan
- Specification of data collection methods, schedule, duration, equipment, and reporting format
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to constant-load motor efficiency projects include the following:

- Method for determining operating hours
- Short-term metering strategy, including usage groups, sampling plan, period of metering and type(s) of meters and data logger(s) to be used
- Assessment of non-operating motors
- Method (s) to account for changes in motor loading (slip) between the baseline and new motor.

18

Variable-Speed Drive Retrofit: Continuous Post-Installation Metering

18.1 ECM Definition

Variable-speed drive (VSD) efficiency projects involve the replacement of existing (baseline) motor controllers with VSD motor controllers. These projects reduce demand and energy use but do not necessarily reduce utility demand charges. Also, VSD retrofits often include the installation of new, high-efficiency motors. Typical VSD applications include HVAC fans and boiler and chiller circulating pumps.

This M&V method is appropriate only for VSD projects in which, for the baseline and post-installation motors, the following conditions apply:

- Electrical demand as a function of operating scenarios, e.g. damper position for baseline or motor speed for post-installation can be defined with spot measurements of motor power draw.
- Operating hours as a function of different motor operating scenarios can be measured.

18.2 Overview of Verification Method

Under Option B, method VSD-B-01 is the only specified technique for verifying VSD projects.

Surveys are required to document existing (baseline) and new (post-installation) motors and motor controls (e.g., motor starters, inlet vane dampers, and VSDs). The surveys should include the following (in a set format) for each motor and control device:

- Nameplate data
- Operating schedule
- Spot metering data
- Motor application
- Location.

Commissioning of VSD operation is expected.

Metering is required on at least a sample of the existing motors to determine baseline motor power draw. Constant-load motors may require only short-term metering to confirm constant loading. For baseline motors with variable loading, short-term metering is done while the motors' applicable systems are modulated over their normal operating range. For variable-load baseline motors, an average kW demand or a kW demand profile as a function of appropriate independent variables (e.g., outside air temperature) may be used in calculating baseline energy use. If baseline independent-variable values are required to calculate the baseline, they will be monitored during the post-installation period.

Post-installation metering is required on at least a sample of motors with VSDs.

Baseline demand and energy use are based on the following:

- Motor operating hours that are measured before or after the VSDs are installed
- A constant-motor kW value that is determined from pre-installation metering.

Alternatively, motor kW can be calculated as a function of independent variables that are monitored during the post-installation period.

Post-installation demand and energy use are based on the following:

- Motor operating hours that are measured after the VSDs are installed
- Motor kW, which is continuously metered or metered at regular intervals during the term of the contract.

Alternatively, motor kW can be calculated as a function of independent variables that are monitored during the post-installation period.

18.3 Calculating Demand and Energy Savings

18.3.1 Baseline Demand and Energy

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have an opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Baseline motor demand will either be any one of the following:

- A constant kW value
- A value that varies per a set operating schedule, e.g., 4,380 hours per year at 40 kW and 4,380 hours per year at 20 kW

- A value that varies as a function of some independent variable, such as outdoor air temperature or system pressure for a variable air volume system.

Steps involved in establishing the baseline demand are as follows:

- Conduct a pre-installation equipment survey
- Perform spot and/or short-term metering of existing motors.

Pre-Installation Equipment Survey

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried. Motor location and corresponding facility floor plans should be included with the survey submittal. The surveys will include the following in a set format:

- Motor and motor control nameplate data
- Motor horsepower
- Load served
- Operating schedule
- Spot metering data
- Motor application and location.

Spot-and Short-Term Metering of Existing Motors

For each motor to be replaced, spot-metered three-phase amps, volts, PF, kVA, kW and motor speed data should be recorded. These data should be entered into a standard form. Such measurements should be made using a true RMS meter with an accuracy at or approaching ±2% of reading. Other factors to measure include motor speed in rpm and the working fluid temperature if the motor serves a fan or pump. The temperature measurement may be taken at either the inlet or outlet of the device, as long as the same location is used for both the baseline and post-installation measurements.

The ESCO will conduct short-term monitoring for constant load, baseline motors to do the following:

- Verify that motor loads are constant
- Normalize spot-metering kW measurement results.

The ESCO will conduct short-term monitoring for variable-load, baseline motors to do the following:

- Develop a schedule of motor kW, e.g., 4,380 hours per year at 40 kW and 4,380 hours per year at 20 kW (see part 16.5).
- Define the relationship between motor kW and the appropriate independent variables, such as outdoor air temperature or system pressure for a variable air-volume system.

The ESCO will conduct short-term metering on all baseline and post-installation VSD-controlled motors or on a randomly selected sample of motors with the same application and/or operating hours. Short-term metering should be conducted and analyzed in the manner discussed in Method CLM-B-01 for constant-load motor applications (see Chapter 17).

18.3.2 Baseline Operating Hours

Baseline motor operating hours can be determined at either of the following times:

- Before ECM installation, if the hours are assumed to be different from post-installation operating hours
- After ECM installation, if the hours are assumed to be the same as post-installation operating hours.

Short-term or long-term metering will be used to be determine operating hours, as discussed in part 18.5.

18.3.3 Adjustments to Baseline Demand and Energy

Before the new motors are installed, adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation. In addition, after ECM installation, adjustments to baseline demand may be required because of factors such as remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

The party responsible for defining the baseline will also identify any non-operating motors. Non-operating equipment is *typically operating* but has broken parts and is *intended for repair.*

18.3.4 Post-Installation Demand and Energy

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency. After VSDs are installed, short-term metering will be conducted for all motors using the same meter and procedures used for the baseline motors, and the results will be entered in a standard survey form. See part 18.3.1.

When recording the motor kW, the motor speed is also recorded. Direct motor rpm measurements can be made or readings can be taken from the VSD control panel.

The power draw of the motors with VSDs will vary depending on the speed of the motor being controlled. In addition, other factors (such as downstream pressure controls) will affect the power draw. With this M&V method, it is assumed that motor power draw is continuously metered or metered for set intervals during the term of the contract, or that motor power draw can be defined as a function of appropriate independent variables, and the independent variables are continuously monitored or monitored for set intervals during the term of the contract.

If less than continuous monitoring is used, the monitored data during the monitoring period will be extrapolated to the full year. A minimum monitoring period of one month is recommended for almost all usage-area groups. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as they do with HVAC systems, it may be necessary to collect data during different times of the year.

Examples of set monitoring or metering intervals are once a month for each season or one randomly selected month during each contract year.

18.3.5 Post-Installation Operating Hours

Post-installation operating hours can be assumed to be either the same as or different from the pre-installation operating hours. If the hours are assumed to be the same before and after the new motors are installed, then post-installation monitoring of motors with VSDs can be used to determine operating hours. Typically, post-installation monitoring will be used because waiting for the results of baseline monitoring could delay VSD installation.

Operating hours can be established per a certain time period (e.g., weekday hours) or per different operating scenarios (e.g., at different VSD speeds). Operating hours monitoring is discussed in part 18.5.

18.4 Sampling

The ESCO will spot meter all of the motors; however, the short- or long-term metering may need to be done only for a sampling of motors.

ESCOs will begin their sampling analyses by classifying existing motors according to applications with identical operating characteristics and/or expected operating hours. Examples of applications include HVAC supply fans, cooling water pumps, heating water pumps, condenser water pumps, HVAC constant-volume return fans, and exhaust fans. Each application will be defined and supported with schematics of ductwork and/or piping as well as control sequences.

For each application or usage group in the project, at least one motor must be subject to short-term metering by the ESCO.

18.5 Monitoring to Determine Operating Hours

Operating hours may be the same before and after the VSDs are installed, or they may be different. Operating hours for the baseline and/or post-installation periods will be determined with short-term or long-term monitoring on at least a sample of motors.

Operating hours will be established for different operating scenarios. Examples include these:

- For a baseline motor: 4,000 hours per year at 50 kW (control valve open) and 4,760 hours per year at 40 kW (control valve closed).
- For a motor with a VSD: 2,000 hours per year at 16 kW (50% speed), 2,000 hours at 30 kW (75% speed), and 4,760 hours at 50 kW (100% speed).

The ESCO will conduct short-term monitoring for a period of time specified in the site-specific M&V plan. The period of time will be proposed by the ESCO and approved or modified by the federal agency.

Monitoring provides an estimate of annual equipment operating hours and energy use. The duration and timing of the installation of run-time monitoring strongly influence the accuracy of operation-hours estimates. Run-time monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the run-time monitoring installation period, the monitoring period should be extended for as many days as the holiday or vacation lasted.

If less than continuous monitoring is used, the operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of *three weeks* is recommended for almost all usage-area groups. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, as they do with HVAC systems, it may be necessary to determine operation hours during different times of the year.

18.6 Equations for Calculating Energy and Demand Savings

Calculate the kWh savings using the following equations:

$$\begin{aligned}&\text{kWh Savings (per each Operating Scenario)}\\&\quad = \text{Operating Scenario Hours} \times \text{kW Savings per each Operating Scenario}\end{aligned}$$

where:

kW Savings = $kW_{baseline}$ - kW_{post}

$kW_{baseline}$ = the kilowatt demand of the baseline motor in a particular operating scenario

kW_{post} = the kilowatt demand of the high-efficiency motor in a particular operating scenario

Operating Scenario = a particular mode of operation defined by an independent variable such as motor speed or valve position

Operating Hours = hours for each operating scenario.

Demand savings may be calculated as:

- Maximum demand reduction:

$$\text{kW Savings}_{max} = (\text{kW}_{baseline} - \text{kW}_{post})_{\text{operating scenario, t}}$$

- Average demand reduction:

$$\text{kW Savings}_{avg} = \frac{\text{Annual kWh Savings}}{\text{Annual Operating Hours}}$$

18.7 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes the following:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the project pre-installation report, adding information on *actual* rather than expected ECM installations.

18.8 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves the project construction, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations
- Specification of site survey plan

- Specification of data collection methods, schedule, duration, equipment, and reporting format
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to VSD projects include the following:

- Definition of operating modes for motors
- Sampling plan for motor power measurements
- Post-installation metering strategy for motor kW or independent variables
- Assessment of non-operating motors.

19

Chiller Replacement: Metering of kW and of kW and Cooling Load

19.1 ECM Definition

This ECM involves chillers used for space conditioning or process loads. Projects can include either of the following:

- Existing chillers replaced with more energy-efficient chillers
- Changes in chiller controls that improve chiller efficiency.

Two M&V methods are described in this chapter. For method CH-B-01, the post-installation chiller energy use is continuously metered or metered at regular intervals. With method CH-B-02, the post-installation chiller energy use and the cooling load are continuously metered or metered at regular intervals.

19.2 Overview of Verification Methods

Surveys are required to document existing (baseline) and new (post-installation) chillers and chiller auxiliaries (e.g., chilled water pumps, cooling towers). The surveys should include the following (in a set format) for each chiller and control device:

- Nameplate data
- Chiller application
- Operating schedules.

Commissioning of chiller operation is expected.

Method CH-B-01—Energy Use Metered
Post-installation chiller energy use is continuously measured or measured during set intervals throughout the term of the ESPC. Baseline energy use is based on the following:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV)
- Stipulated cooling loads or cooling loads calculated from the measurement of post-installation chiller energy use.

Method CH-B-02—Energy Use and Cooling Load Metered
Post-installation chiller energy use and cooling loads are continuously measured or measured during set intervals throughout the term of the ESPC. Baseline energy use is based on the following:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV)
- Cooling loads measured during the post-installation period.

19.2.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have an opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are these:

- Conduct a pre-installation equipment survey.
- Define the chiller efficiency (see Method CH-A-01) or meter the existing chillers (see Method CH-A-02).

Pre-Installation Equipment Survey
In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Chiller location and corresponding facility floor plans should be included with the survey submittal. The surveys will include the following in a set format:

- Chiller and chiller auxiliaries nameplate data
- Chiller age, condition, and ratings
- Load served
- Operating schedule
- Chiller application
- Equipment locations.

Chiller performance can either be stipulated or measured.

Stipulated Chiller Efficiencies
The most common source of chiller performance data is the manufacturer. For existing chillers, the “nameplate” performance ratings may be downgraded on the basis of the chiller's age and/or condition. Chiller efficiency can be presented in several formats, depending on the type of load data that will be stipulated. Possible options include annual average kW/ton expressed as IPLV (for example, per the appropriate standards of the Air-Conditioning and Refrigeration Institute) or kW/ton per incremental cooling loads.

Metering of Existing Chillers

The data collected to characterize the performance of the chiller depends on whether the chiller's efficiency is sensitive to the condenser and chilled water temperature or not. Volume II of the Final Report for ASHRAE Research Project 827-RP, *Guidelines for In-Situ Performance Testing of Centrifugal Chillers*, provides detailed instructions for developing both a temperature-dependent and temperature-independent model of chiller performance. The models use linear regressions on metered data to characterize the performance of the chiller over a range of onditions. The wider the range of conditions experienced during the metering, the more accurate the models will be.

For temperature-independent chillers (chillers whose condenser and chilled water temperatures are close to constant), the following data will need to be collected:

- Chiller kW
- Chilled water flow, entering and leaving temperatures for calculating cooling load.

For chillers subject to varying condenser and chilled water temperatures, all of the data noted above must be collected along with the following:

- Condenser water supply temperature
- Chilled water return temperature.

If other features of the cooling plant are also modified by the proposed measures, they'll need to be metered as well. For instance, if the condenser water pumps, chilled water pumps, or cooling tower fans are affected, their demand (kW) should also be metered.

As much as possible, these data should be entered into standard forms. Such measurements should be made using a meter with an accuracy at or approaching ±2% of reading for power measurements and ±5% for flow measurements. Multiple measurements are made while the cooling systems are operating at different loads so that the complete range of chiller performance can be evaluated. Thus, the baseline metering typically requires a time period of at least several weeks when the cooling load is expected to vary over a wide range; often, more time is required.

19.2.2 Post-Installation Demand and Energy

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency.

Chiller energy use and demand profile will be measured either continuously throughout the term of the ESPC contract or at set intervals during the term of the contract (e.g., one month during each of the four seasons). The intervals must adequately define the full range of chiller performance.

If data are not collected continuously, the data that are collected are used to develop a model of the chiller performance, which can be applied when chiller performance isn't measured.

The data collected to characterize the performance of the chiller depends on the whether the chiller's efficiency is sensitive to condenser and chilled water temperature or not. Volume II of the Final Report for ASHRAE Research Project 827-RP, *Guidelines for In-Situ Performance Testing of Centrifugal Chillers*, provides detailed instructions for developing both a temperature-dependent and temperature-independent model of chiller performance. The models use linear regressions on metered data to characterize the performance of the chiller over a range of conditions. The wider the range of conditions experienced during the metering, the more accurate the model will be.

For temperature-independent chillers (chillers whose condenser and chilled water temperatures are close to constant), the following data will need to be collected:

- Chiller kW
- Chilled water flow, entering and leaving temperatures for calculating cooling load

For chillers subject to varying condenser and chilled water temperatures, all of the data noted above must be collected along with the following:

- Condenser water supply temperature
- Chilled water return temperature

If other features of the cooling plant are also modified by the proposed measures, they must be metered as well. For instance, if the condenser water pumps, chilled water pumps, or cooling tower fans are affected, their demand (kW) should also be metered.

As much as possible, these data should be entered into standard forms. These measurements should be made using a meter with an accuracy at or approaching ±2% of reading for power measurements and ±5% for flow measurements. Multiple measurements are made while the cooling systems are operating at different loads so the complete range of chiller performance can be evaluated. Thus, the baseline metering typically requires a time period of at least several weeks during a time when the cooling load is expected to vary over a wide range; often, more time is required.

19.2.3 Cooling Load

Cooling load does not have to be measured to determine post-installation energy use and demand because the post-installation chiller energy use is metered with these two M&V methods. The baseline-cooling load, however, must be determined to calculate baseline energy use and demand.

Method CH-B-01—Energy Use Metered

With this method, cooling load is not measured; therefore, baseline cooling load is either stipulated or calculated from post-installation chiller energy use measurements.

Possible sources of stipulated baseline chiller loads are these:

- Pre-installation metering of cooling loads by the ESCO or federal agency
- Results from other projects in similar facilities.

If stipulated loads are used, a simple, temperature-independent model of chiller performance should be used, since the condenser water return temperature would be very difficult to stipulate successfully.

Baseline and post-installation cooling loads may be different. Typical weather data or actual weather data can be used to determine cooling loads. The problem with stipulating cooling loads is savings may be inappropriately biased because comparison of the baseline and post-installation energy use of different cooling loads.

Method CH-B-02—Energy Use and Cooling Load Metered

Cooling loads are measured with this method. Therefore, baseline cooling loads are based on the post-installation cooling load. Data that should be metered include the following:

- Chilled water flow
- Chilled water entering and leaving temperatures (air-flow measurements are required for DX systems)
- Outside air temperature or weather data (for reference).

If a temperature-dependent model of chiller performance is used, the condenser water return temperature should also be metered.

19.2.4 Equations for Calculating Energy and Demand Savings

Calculate the kWh savings using the following equations:

$$\begin{aligned}&\text{kWh Savings}\\&\quad = [(\text{Baseline Cooling Load in Ton-Hours}) \times (\text{Baseline kW/Ton})] - \text{Post-Installation kWh}\end{aligned}$$

where:

Cooling Load in Ton-Hours = stipulated, measured, or calculated

Baseline kW/ton = stipulated or measured existing chiller performance

Post-installation kWh = measured for the new chiller(s).

Demand savings may be calculated as follows:

- Maximum demand reduction:

$$\text{Savings}_{max} = (\text{kW}_{baseline} - \text{kW}_{post}) \text{ at maximum cooling load, t}$$

- Average demand reduction:

$$\text{kW Savings}_{avg} = \frac{\text{Annual kWh Savings}}{\text{Annual Operating Hours}}$$

19.3 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes the following:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the Project Pre-Installation Report, adding information on *actual* rather than expected ECM installations.

19.4 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves the project construction, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations
- Source of baseline chiller performance and/or cooling loads

- Specification of site survey plan
- Specification of data collection methods, schedule, duration, equipment, and reporting format
- Identification and resolution of any other M&V issues.

Specific M&V issues that must be addressed and that are related to chiller replacement projects include these:

- Determination of whether to meter cooling load
- Duration of the monitoring.

20

Generic Variable Load: Continuous Post-Installation Metering

20.1 Project Definition

This M&V method plan covers projects that improve the efficiency of end uses that exhibit variable energy demand and/or variable operating hours. Here are some examples:

- Replacing motors that serve variable loads with high-efficiency motors
- Upgrading building automated systems
- Installing new air-conditioning equipment
- Installing thermal insulation.

For this M&V method, the savings associated with the ECMs must be verified with end-use metering.

20.2 Overview of Method

The ESCO will audit existing systems to document relevant components; e.g., piping and ductwork diagrams, control sequences, and operating parameters. The ESCO will also document the proposed project and expected savings. All of the existing systems, or a representative sample, will be metered by the ESCO to establish regression-based equations (or curves) for defining baseline system energy use as a function of appropriate variables, e.g., weather or cooling load.

Once the ECM is installed, there are two general approaches for determining savings:

- Continuously measuring post-installation energy use and the appropriate variables. Post-installation variable data are used with the baseline equations to calculate baseline energy use.
- Continuously measuring only the appropriate post-installation variables. The post-installation variable data are used with the baseline and post-installation equations to calculate baseline and post-installation energy use. With this approach, the ESCO will conduct metering to determine the post-installation relationship between input energy and the appropriate variables after the project is installed.

The ESCO will apply the results of the post-installation metering to determine the difference between pre-installation and post-installation input energy use (and demand). This difference represents the system savings.

20.3 Metering and Calculating Baseline Demand and Energy Savings

20.3.1 Audit Baseline System

The ESCO will audit system(s) to be affected by projects to document all relevant components, such as motors, fans, pumps, and controls. For each piece of equipment, documented information will include the manufacturer, model number, rated capacity, energy-use factors (such as voltage, rated amperage, MBtu/hr), nominal efficiency, the load served, and a listing of independent variables that affect system energy consumption. Equipment location and corresponding facility floor plans should be included with the survey submittal.

20.3.2 Establishing Baseline Model

The ESCO will meter system input energy (e.g., kWh, Btu) and demand (e.g., kW, Btu/hr) over a representative time period before any efficiency modifications are made (note that demand is measured if contract payments include a demand savings-based component). This metering will be applied to devices that will be directly affected by the ECM. The duration of input metering will be long enough to document the full range of system operation. The ESCO will propose an appropriate duration in the site-specific M&V plan, subject to approval by the federal agency on a case-by-case basis. Typically, observations will be made at 15-minute intervals, unless the ESCO demonstrates that longer intervals are sufficient and this is approved by the federal agency.

Energy Standards

If the project is subject to any energy standards or minimum performance standards, these standards may need to be accounted for in the baseline model.

If multiple, similar equipment components or systems are to be modified (e.g., ten supply fans), the ESCO may propose metering only a sample in the site-specific plan.

Variable Measurements

While the input energy use is being monitored, the ESCO will meter one or both of the following at the same time:

- Independent variables that affect the energy and demand use are ambient temperature, control set points, and building occupancy.
- Dependent variables (system output) that indicate the energy and demand use. This monitoring will clearly quantify output in units that directly correspond to system input. Examples of dependent variables are tons of cooling, MBtu of heating load, and gallons of liquid pumped.

Baseline Model(s)

Most efficiency projects and systems can be directly influenced by highly variable independent variables such as weather conditions. For these projects, the ESCO may choose to develop a regression model that links independent variable data to energy input. The ESCO can present specific methods for doing this in the site-specific M&V plan, and these methods will be considered for approval by the federal agency.

The ESCO will combine the results of energy input metering and variable(s) monitoring to establish the pre-installation relationship between the quantities. This relationship will be known as the "System Baseline Model" and will probably be presented in the form of an equation. The ESCO may use regression analysis to develop such an equation, although other mathematical methods may be approved. If regression analysis is used, the ESCO will demonstrate that it is statistically valid. These are some examples of criteria for establishing statistical validity:

- The model makes intuitive sense; e.g., the explanatory variables are reasonable, the coefficients have the expected sign (positive or negative), and they are within an expected range (magnitude).
- The modeled data are representative of the population.
- The form of the model conforms to standard statistical practice.
- The number of coefficients are appropriate for the number of observations (approximately no more than one explanatory variable for every five data observations).
- The T-statistic for all key parameters in the model is at least 2 (95% confidence that the coefficient is not zero).
- The model's R2 (coefficient of determination) is reasonable given the type of data being modeled.
- All data entered into the model are thoroughly documented, and model limits (the range of independent variables for which the model is valid) are specified.

The federal agency will make the final determination on the validity of models and monitoring plans and may request additional documentation, analysis, and/or metering from the ESCO, as necessary.

Note: The ESCO must carefully investigate systems and select data input and output for monitoring that exhibit direct relationships to energy use. For example, some processes may use the same amount of energy regardless of the amount of units produced. In such cases, the ESCO must carefully analyze systems to identify a quantifiable output that exhibits a direct relationship to the input energy.

20.4 Post-Installation Metering and Calculating Savings

Two approaches are defined here for calculating savings:

- Continuously measuring post-installation energy use (and demand) and the appropriate variables. The post-installation variable data are used with the baseline equations to calculate baseline energy use (and demand).
- Continuously measuring the appropriate post-installation variables. The post-installation variable data are used with the baseline and post-installation equations to calculate baseline and post-installation energy use (and demand).

20.4.1 Calculating Savings by Metering Post-Installation Energy and Variables

After installing the ECM, the ESCO will continuously meter the system energy input and monitor the output (e.g., tons of cooling) or independent variables (e.g., weather) over the life of the claimed energy savings. Metering and monitoring will be done in the same way as the monitoring done to model the performance of the baseline system.

For this option, the post-installation metered input energy will be used directly in the savings calculation. The monitored data will be used in the System Baseline Model to calculate pre-installation energy input.

Energy savings over the course of a single observation interval will be calculated by the ESCO using the following equation (assuming an electric measure):

$$\text{Energy Savings}_i = (kW_{baseline} - kW_m) \times T_i$$

where:

$kW_{baseline}$ = Baseline kW calculated from System Baseline Model and corresponding to the same variable (e.g., time interval, system output, weather, conditions) as kW_m

kW_m = Measure kW obtained through continuous post-installation metering

T_i = Length of time interval.

(Note that kW is used in this equation, but other factors such as Btu/hr may be appropriate).

For a particular observation interval, the ESCO will apply the monitored data to the Baseline System Model in order to determine what the baseline system energy input would have been. From this amount, the ESCO will subtract the metered system post-installation input. Energy savings are determined by multiplying this difference by the length of the observation interval.

20.4.2 Calculating Savings by Metering Post-Installation Variables

The ESCO may meter the post-installation system energy input and monitor the post-installation conditions in order to develop a Post-Installation System Model. The ESCO would then monitor system output (and/or other relevant variables) during a representative period on a regular basis. This representative period will be similar to the period over which the System Baseline Model monitoring occurred. If regression analysis is employed, the Post-Installation System Model will also be subject to the same validity criteria specified in part 20.3.2.

When choosing this alternative, the ESCO will use two equations to calculate savings or one equation to calculate changes in energy use. The ESCO will apply monitored data to the Baseline System Model to obtain the baseline system energy input. The ESCO will then apply the same monitored data to the Post-Installation System Model to obtain the post-installation system energy input. The monitored data (e.g., ambient temperature) may be obtained continuously or for selected intervals (e.g., once a month for each season for weather-dependent measures) during the term of the contract. The ESCO may then calculate the savings by taking the difference of the baseline and post-installation system data input and multiplying by the appropriate time interval.

20.4.3 Actual or Typical Data

To determine savings using dependent or independent variables, either use (a) the actual measured values as they occur during the term of the agreement or (b) typical values for calculating savings. For example, with respect to weather data, it may be more appropriate to use typical-year data rather than actual weather data.

20.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a project pre-installation report that includes:

- A project description and schedule
- A pre-installation equipment survey
- Estimates of energy savings
- Documentation on utility billing data
- Projected budget
- Scheduled M&V activities.

If the federal agency defines the baseline condition, the ESCO must verify an agreed-to pre-installation equipment survey.

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the project pre-installation report, adding information on *actual* rather than expected ECM installations.

20.6 Site-Specific Measurement and Verification Plan

The site-specific M&V approach may be pre-specified in the ESPC between the federal agency and the ESCO and/or agreed to after the award of the project. In either case, before the federal agency approves the project construction, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculation methods, including the models used
- Specification of site survey plan
- Specification of the data to be collected and the data collection methods, schedule, duration, equipment, and reporting format
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to these types of generic variable load projects include the following:

- Determination of metering approach, i.e., monitoring of energy uses or post-installation variable
- Identification of appropriate variables
- Duration of monitoring.